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Mini Review

Looking Into the Plateau of Oxygen Uptake

Rodolfo Velasque[1]* and Fernando AMS Pompeu[1,2]

[1]Biometrics Laboratory, College of Physical Education and Sports at Rio de Janeiro Federal University (LADEBIO/EEFD/UFRJ), Brazil

[2]Physical Education Graduate Program at Rio de Janeiro Federal University (PPGEF/UFRJ), Brazil

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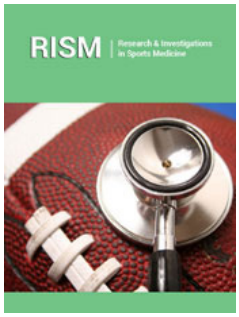

***Corresponding author:** Rodolfo Velasque, Biometrics Laboratory, College of Physical Education and Sports at Rio de Janeiro Federal University (LADEBIO/EEFD/UFRJ), Rio de Janeiro, Brazil

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Abstract

Sport scientists have been studying adaptations to maximal cardiorespiratory effort for decades. A plateau of the oxygen uptake ($\dot{V}O_{2pl}$) nearby the maximal effort, which means that the $\dot{V}O_2$ stops to increase despite the workload progress, is one of these interesting physiological responses. Although the $\dot{V}O_{2pl}$ raises a great interest, this phenomenon is not observed in a large number of Graduate Exercise Tests. It might occur because of the $\dot{V}O_2$ kinetics, biological characteristic of the tested individuals, exercise protocols and $\dot{V}O_{2pl}$ cutoff criteria. Therefore, this lack of methodological standards has provoked a non-consensual approaching about the plateau occurrence. Thus, new studies in which a better control of those variables occurs must be done, in order to understand this complex phenomenon.

Keywords: Aerobic capacity; Maximal oxygen consumption; Cardiovascular health; $\dot{V}O_{2max}$

Abbreviations: $\dot{V}O_{2pl}$: Plateau in Oxygen Uptake; $\dot{V}O_{2max}$: Maximal Oxygen Uptake; $\dot{V}O_2$; Oxygen Uptake

Introduction

Researchers in exercise sciences have been investigating cardiovascular, respiratory and metabolic responses to maximal effort since the beginning of the XX Century. However, in the end of the last century, an important debate was raised about the maximal oxygen uptake ($\dot{V}O_{2max}$) [1,2]. It was very important, because not only $\dot{V}O_{2max}$ can show the maximal rate in which the oxygen can be inspired, transported and used by active muscles during maximal effort, but this parameter can also be applied to understand the cardiovascular health, effect of training and to prescribe exercises [3,4].

By definition, the $\dot{V}O_{2max}$ is reached during an endurance test when oxygen uptake remains constant despite an increment of the exercise intensity. Therefore, there is a $\dot{V}O_2$ levelling off, which is required as the gold standard criterion of the $\dot{V}O_{2max}$. This phenomenon is called oxygen uptake plateau ($\dot{V}O_{2pl}$) [5,6].

Taylor et al. [7] were the first group to study the $\dot{V}O_{2pl}$. They performed a 3-minute discontinuous exercise protocol, in which the workloads were applied on separate days with a fixed velocity and increasing the treadmill slope. These authors showed that the average of the oxygen uptake increments was 299.3 ± 86.5 mL·min^{-1} (~ 4.18 ± 1.1mL·min^{-1}) in 115 subjects. Based on these data, the authors concluded that $\dot{V}O_2$ an increment less than half of this average, or 150mL·min^{-1} (~2.1mL·min^{-1}), means that the $\dot{V}O_{2max}$ was achieved. About this criterion they wrote that: "[...] there is small chance of making an error in deciding that the maximal oxygen intake had been reached" [7].

The $\dot{V}O_{2pl}$ was extensively investigated by many researchers [7-9], however, a considerable number of subjects, who performed an endurance test, have not shown this phenomenon. This problem can occur because of many factors, which can interfere in the $\dot{V}O_{2pl}$ occurrence, such as: $\dot{V}O_2$ kinetics, group of tested individuals, exercise protocols and $\dot{V}O_{2pl}$ cutoff selected criterion.

Influencing Factors on $\dot{V}O_{2pl}$ Occurrence

It can be seen in many studies about oxygen kinetics that subjects with a faster oxygen kinetics and lower oxygen deficit are more likely to show the oxygen uptake plateau [10]. It happens because these subjects could sustain an intense effort near to $\dot{V}O_{2pl}$ for a longer period of time and postponed the exhaustion. These adaptations in oxygen kinetics are caused by a greater anaerobic capacity [11,12]. Additionally, it is possible that a shorter time effort to reach the $\dot{V}O_{2pl}$ may represent a faster oxygen kinetics and a higher tolerance to the intense exercise.

The cutoff criterion presented by Taylor et al. [7] (150mL·min^{-1} / 2.1mL·kg^{-1}·min^{-1}) is widely used to point out the $\dot{V}O_{2pl}$ [13]. However, in order to avoid false-positive determination of this phenomenon, other studies about its cutoff criteria should be done. Astrand [8], for example, suggested that the rigorous standard of the 80mL·min^{-1} might be better to determine the $\dot{V}O_{2pl}$. Moreover, Astorino et al. [14], investigated the $\dot{V}O_{2pl}$ occurrence in 16 men, who performed a maximal exercise test on a cycle ergometer. They observed that 100% of the $\dot{V}O_{2pl}$ happened, if a smaller broad criterion (≤ 50mL·min^{-1}) is applied. Myers et al. [15] concluded, in a study with only six active males, that when the slope was equal to zero in the regression between $\dot{V}O_2$ and time, we have the best criterion of the $\dot{V}O_{2pl}$.

Astorino et al. [9], studied different groups of individuals during an incremental test, and they observed when the cutoff criterion was ≤ 50mL·min^{-1}, then the $\dot{V}O_{2pl}$ occurred in 66% of endurance-trained subjects, 82% in recreational athletes and 60% in strength-trained subjects. However, when these authors used the slope of the $\dot{V}O_2$ *versus* time regression, a non-significant difference from zero was observed, i.e. the $\dot{V}O_{2pl}$ was showed (O_2 collected during the last 30 seconds of the test). Even though the time of the gas collection samples increased during the last 60 seconds of the test, the slope is still different from zero in four out of the nine subjects who finished the test [9].

When Duncan et al. [16] investigated the occurrence of $\dot{V}O_{2pl}$ with different exercise types, considering the 150mL·min^{-1} as the cutoff criterion, they showed the plateau in 60% of the discontinuous and 50% of continuous protocols. On the other hand, studies with discontinuous tests found different incidences of the $\dot{V}O_{2pl}$ [17,18]; thus, there is a non-consensus about this point. Furthermore, Duncan et al. [16] were the only group who compared continuous and discontinuous tests in intra-subject experimental design. It should be concluded that further studies about the presence or absence of $\dot{V}O_{2pl}$ with different groups of individuals and with different protocols should be done [6].

Criticism about $\dot{V}O_{2pl}$

Some studies have questioned the validity of the $\dot{V}O_{2pl}$, because of the low occurrence of this phenomenon, in special during a fast incremental test. These studies based their conclusions on the premise that: "[...] the absence of a plateau indicates adequate muscle oxygenation during maximal exercise" and that the end of the effort cannot be interpreted as an accumulation of anaerobic metabolites [2,19]. However, Niemeyer et al. [6] wrote a critical review, in which they raised that: "[...] the assumption that the absence of a $\dot{V}O_{2pl}$ indicates adequate muscle oxygenation per se and no need for muscular anaerobic energy provision reflects a misinterpretation of energy metabolism". Moreover, Pompeu [20] showed that these studies had important logical and experimental failures, which could demonstrate neither the absence of the $\dot{V}O_{2pl}$ nor any other hypothesis to explain the exhaustion. In Pompeu's papers [20,21] a criticism about the basic scientific approach in many of these studies are raised and they are strongly recommended as a deep critical review about this topic (Figure 1).

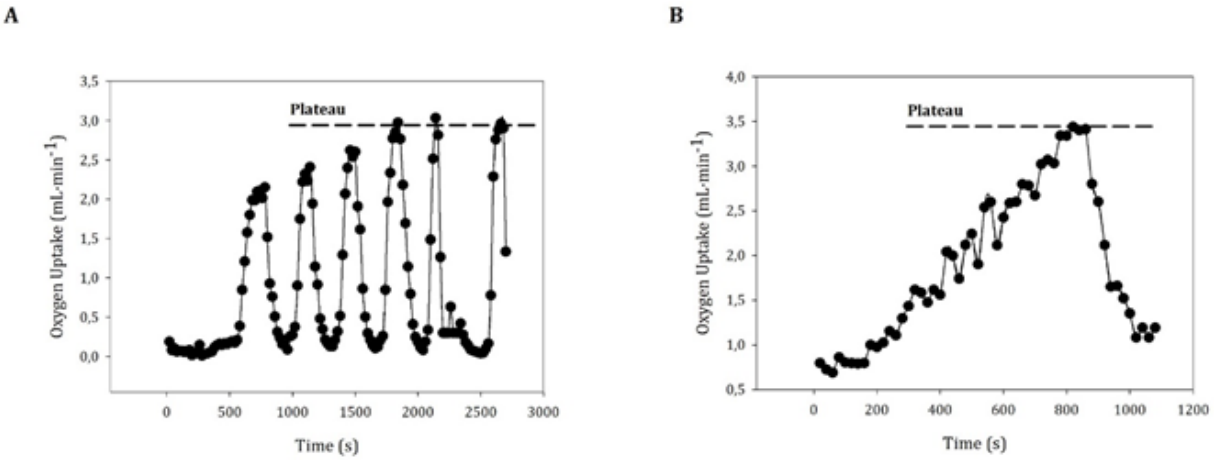

Figure 1: Examples of Plateau in laboratory tests with O_2 measurements.
Figure 1 Legend: The figure describes examples of two real tests performing at Biometrics Laboratory (LADEBIO), within females actives subjects. A - represents a discontinuous treadmill test with 3-min stages, increasing the velocity to maximal effort. B - represents a continuous cycle test, increasing the intensity to maximal effort. The plateau showed in figure is symbolic only, because for considering a real plateau, is necessary determine a cut-off. Each circle represents one O_2 measurement in metabolic analyzer.

The Verification Phase

In order to increase the chance of achieving the $\dot{V}O_{2pl}$, several studies had combined continuous and discontinuous tests, which introduce a verification phase [5,22]. The protocol should start with a maximal incremental test, and, after a long rest, it has to be followed through with a supra-maximal test. If the peak of the $\dot{V}O_2$ between these two tests is not different, according to the cutoff criterion previously defined, then the $\dot{V}O_{2pl}$ and consequently the $\dot{V}O_{2max}$ were achieved [5]. A minimum time period when the subject must endure with the supra-maximal workload must be established according to the $\dot{V}O_2$ fast kinetics phase, in order to avoid false-positive results. This period can be ~2min for trained adults, ~3min for active adults and ~5min for untrained people [6].

Conclusion

In conclusion, the plateau of the maximum oxygen consumption is a very important physiological phenomenon. However, methodological standards to correct the difference among cutoff criteria, individual fitness and protocol tests are not widely accepted. Therefore, future studies should investigate the detection criterion and the incidence of the plateau during maximal effort. Otherwise, this complex physiological mechanism will not be completely understood.

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